Western North Pacific Tropical Cyclone Formation and Structure Change in TCS-08

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Award Number: N0001411WX20094

LONG-TERM GOALS

The long-term goal of this project is to develop a better understanding of mesoscale and synoptic-scale processes associated with the entire life cycle of tropical cyclones in the western North Pacific. The inability to correctly identify tropical cyclone formation over the period of 24 h – 48 h poses a threat to shore and afloat assets across the western North Pacific. Furthermore, once a tropical cyclone has formed the predictability of structure changes during intensification of tropical cyclones is very low, which is due to complex physical processes that vary over a wide range of space and time scales. Periods of reduced predictability occur throughout the tropical cyclone life cycle, which includes the decaying stage. Because decaying tropical cyclones often transition to a fast-moving and rapidly-developing extratropical cyclone that may contain gale-, storm-, or hurricane-force winds, there is a need to improve understanding and prediction of the extratropical transition phase of a decaying tropical cyclone. The structural evolution of the transition from a tropical to an extratropical circulation involves rapid changes to the wind, cloud, and precipitation patterns that potentially impact maritime and shore-based facilities.

OBJECTIVES

A primary objective is to increase understanding of the formation of a tropical cyclone from what may have been a disorganized area of deep convection or a weak pre-existing cyclonic disturbance. Over the monsoon environment of the tropical western North Pacific, pre-tropical cyclone disturbances range from low-level waves in the easterlies to large monsoon depressions. An objective of this project is to define factors that impact the large-scale atmospheric and oceanic controls on tropical cyclone formation.

A long-term goal is to understand the relative role(s) of mesoscale processes in organizing a pre-tropical cyclone disturbance such that it may begin to intensify as a tropical cyclone. A specific

Report Documentation Page			*Form Approved* *OMB No. 0704-0188*
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1. REPORT DATE **30 SEP 2011**	2. REPORT TYPE		3. DATES COVERED **00-00-2011 to 00-00-2011**
4. TITLE AND SUBTITLE **Western North Pacific Tropical Cyclone Formation and Structure Change in TCS-08**			5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)			5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School,Department of Meteorology,Monterey,CA,93943**			8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**			
13. SUPPLEMENTARY NOTES			
14. ABSTRACT			
15. SUBJECT TERMS			

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

objective is to examine processes that define relative contributions of low-level vorticity in deep convective towers versus mid-level circulations embedded in stratiform regions of mature mesoscale convective systems. This objective addresses the predictability associated with the location, timing, and rate of tropical cyclone formation over the western North Pacific.

Additional objectives address the characteristic structure changes as a tropical cyclone intensifies, matures, then proceeds into extratropical transition. A particular focus is identification of key structural characteristics that limit the predictability of recurvature and the start of the extratropical transition process.

APPROACH

The Tropical Cyclone Structure-2008 (TCS-08) program resulted in direct observations of the entire life cycle of tropical cyclones over the western North Pacific. This included development and non-development of tropical cloud clusters, intensity and structure changes of mature tropical cyclones, and decay and extratropical transition of poleward-moving tropical cyclones.

A unique data set in the TCS-08 field experiment was the Electra Doppler Radar (ELDORA) radar observations of reflectivity and three-dimensional wind fields. The availability of data from ELDORA has provided the opportunity for analyses of key structural characteristics contained in deep convection in pre-tropical cyclone disturbances, outer rainbands of mature tropical cyclones, and the convective and wind distribution in the inner core of a tropical cyclone.

An additional unique data set from TCS-08 is comprised of Airborne Expendable Bathythermographs (AXBTs) that were deployed in several mature tropical cyclones during the field program. The AXBT data set is used in conjunction with analyses from the Naval Research Laboratory (NRL) East Asian Seas Nowcast/Forecast System (EASNFS) to examine the relative roles of oceanic and atmospheric factors on tropical cyclone intensity change.

WORK COMPLETED

Several case studies from the TCS-08 data set have been selected for examination in terms of the detailed wind and convective structures plus the determination of impacts on the vertical profiles of latent heat release that influences the roles of the convection with respect to the circulations in which the convection is embedded. Data from the ELDORA, was operated on the NRL P-3 and provided high-resolution reflectivity, and winds from 1-17 km in the vertical, are utilized to define fine scale three-dimensional wind fields, thermodynamic characteristics, and vertical profiles of latent heat release. Precipitation radar (PR) data from the Tropical Rainfall Measuring Mission (TRMM) satellites are also used to define vertical profiles of latent heat release. Five TCS-08 cases [TY Jangmi (Case I), pre-TD Nuri (Case II), pre-TD Jangmi (Case III), pre-Sinlaku (Case IV), and TCS-025 (Case V)] in which the PR overpasses were well correlated with the ELDORA observations have been examined. These cases include the mature, pre-developing and developing phases of tropical cyclones, and a non-developing system. Using the derived three-dimensional winds, the horizontal and vertical gradient of pressure and temperature perturbations are calculated from the momentum and thermodynamic equations. Here the temperature perturbation field is calculated relative to the nearest dropsonde sounding from the US Air Force C-130 or the Taiwan DOTSTAR. The retrieved

temperature field is used with the derived vertical motion field to calculate the vertical profile of latent heat release defined from in-situ observations with the remotely-sensed data from the TRMM PR.

As an examination of a non-developing tropical system during TCS-08, the convective feature labeled TCS-025 has been examined in detail. The TCS-025 feature contained multiple mesoscale convective systems (MCSs) that were observed to form in a region between two upper-level cold low-pressure centers. Two TCS-025-related MCSs were examined with observations from Air Force WC-130J and Navy Research Lab P-3 flights. Observations were made by dropsonde measurements from both aircraft and by the Electra Doppler Radar (ELDORA) on the NRL P-3. The Advanced Weather Research and Forecasting numerical model (WRF-ARW) has been used to examine the roles that MCS development had in the formation of the mesoscale circulations identified in observations.

The AXBT profiles from deployments in Typhoon (TY) Sinlaku and TY Jangmi during TCS-08 have been used to characterize the ocean conditions over which the tropical cyclones were passing. From the AXBT profiles, ocean heat content (OHC), depth of the mixed layer, and average temperature of the top 100 m have been computed. The observed ocean parameters in conjunction with vertical wind shear are examined with respect to intensity variations of each tropical cyclone.

The structural evolution of Typhoon (TY) Sinlaku during TCS-08 has been examined as it weakened under extreme vertical wind shear then re-intensified to typhoon intensity, then began extratropical transition as it moved into the midlatitudes. The combined ELDORA, dropsonde, and aircraft flight-level data provide a unique distribution of data throughout the extratropical transition process.

RESULTS

The examination of AXBT-derived OHC (DePalma 2011) throughout the intensification stages of TY Sinlaku and TY Jangmi have identified strong correspondence among ocean characteristics, the distribution of vertical wind shear, and tropical cyclone intensity changes (Fig. 1). As TY Sinlaku was intensifying, the storm passed over a cold ocean eddy between 0600 UTC 9 September and 0000 UTC 10 September. Over the latter portion of the passage over the cold eddy, intensification was halted for a period of 12 h. During this time, the vertical wind shear was consistently low and the reduction in intensification rate was attributed to the passage over the cold eddy. Immediately following the passage over the cold eddy, Sinlaku moved over a warm eddy. The storm reached peak intensity immediately after passing over the warm eddy. Again, the vertical wind shear was consistently low during this period. Immediately following passage over the warm eddy and the typhoon peak intensity, the storm passed over a cold eddy and the intensity dropped markedly.

DePalma (2011) compared the AXBT-derived OHC to the NRL EASNFS model-analyzed OHC that was interpolated to the location of each AXBT observation. Results indicate that the NRL EASNFS represents the general ocean features quite well with deviations in magnitude and location of boundaries of the warm and cold eddies.

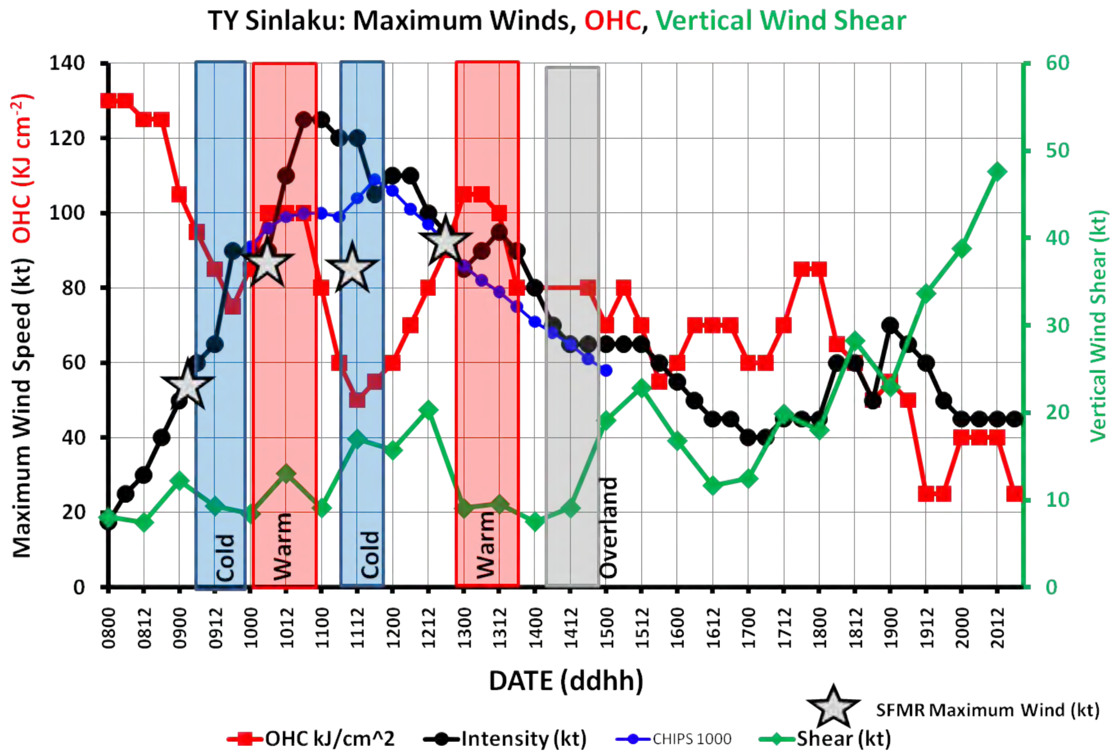

Fig. 1 Typhoon Sinlaku OHC (kJ cm^{-2}) from the NRL EASNFS, intensity (kt) in 6-h increments and vertical wind shear (kt) in 12-h increments from the European Center for Medium-Range Weather Forecasts (ECMWF) analysis. Forecast of storm intensity from the Coupled Hurricane Prediction System are defined in blue. The surface winds measured by aircraft are defined by the large stars. Colored boxes define periods when Sinlaku traversed significant ocean features or land.

Park and Elsberry (2011) have documented from the ELDORA observations that the developing tropical cyclones during TCS-08/T-PARC have a maximum of latent heating lower in the troposphere than the non-developing tropical cyclones. Whereas the developing cyclones have larger maximum heating rates than evaporative cooling rates, the non-developing cyclones tend to have offsetting maximum heating and cooling rates so that there is little or no net heating in the deep convective columns and thus little or no deepening of the surface pressure. Park and Elsberry (2011) also document a serious deficiency in the evaporative cooling rates from the Tropical Rainfall Measurement Mission (TRMM) observations during all six ELDORA missions in which collocated TRMM observations were available. Thus, an improved TRMM algorithm that removes this evaporative cooling deficiency is required if the TRMM observations are going to be used for tropical cyclone formation (intensification or structure change) studies.

Park et al. (2011) have compared the latent heating and evaporative cooling rates simulated by COAMPS and by the WRF-ARW in similar convective clusters as calculated by Park and Elsberry (2011) from the ELDORA radar observations. The COAMPS and WRF models are shown to have maximum heating rates in deep convection that are two to three times larger than from the ELDORA observations. Although the two models also have maximum evaporative cooling rates that are larger than those from ELDORA, these maximum cooling rates are considerably smaller than the maximum

heating rates. Thus, the two model simulations tend to have excessive net heating rates in the deep convective columns that appear to account for the common tendency for these two models to over-deepen both the developing cyclones and the non-developing cyclones.

Analyses of the structural evolution of TY Sinlaku with high-resolution wind and reflectivity data from ELDORA as the storm begins the process of extratropical transition have revealed the role of vertical wind shear in defining structural variations related to the start of the transformation to a midlatitude cyclone. These structural variations are being examined to define the impact on the distribution of horizontal wind radii as the storm starts the process of extratropical transition.

Elsberry et al. (2011) have extended the analysis of the performance of the weekly ECMWF 32-day ensemble forecasts to the 2009 typhoon season, which had more typical monsoon trough conditions. The 2009 season also had more tropical cyclones and Elsberry et al. evaluated the performance for six intense typhoons, six moderate typhoons, and three strong tropical storms. Seventeen of the 23 tropical cyclones evaluated occurred as multiple tropical cyclone scenarios, which are inherently more difficult to predict because of their direct or indirect interactions. Some of the notably difficult storm tracks were Typhoons Lupit and Parma, and although the formation location was generally well forecast, the tracks after the typhoon strongly interacted with the midlatitude flow were not predictable. Overall, the performance of the ECMWF 32-day ensemble was better for the 2009 typhoon season than for the 2008 season.

IMPACT/APPLICATIONS

The research being conducted on the comprehensive data sets gathered during the TCS-08 field program will result in increased accuracy associated with the prediction of tropical cyclone formation, intensification, and structural changes. Additionally, the unique observations of the air-ocean conditions in the environment of mature tropical cyclones over the western North Pacific provide a unique capability to identify the relative roles of environmental factors on tropical cyclone intensity change.

TRANSITIONS

Following the compilation and analysis of the wide range of TCS-08 data sets, research results that identify factors responsible for the variability in tropical cyclone formation, intensification, and structure change will transition into a variety of products that will benefit operational forecasting of these tropical cyclone characteristics. These may be stand-alone products, satellite-based products, improvements to numerical models, etc. Final transition of the research will result in increased predictability associated with tropical cyclones that impact operations of the U.S. Navy across the western North Pacific.

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